X-rays and Planet Formation

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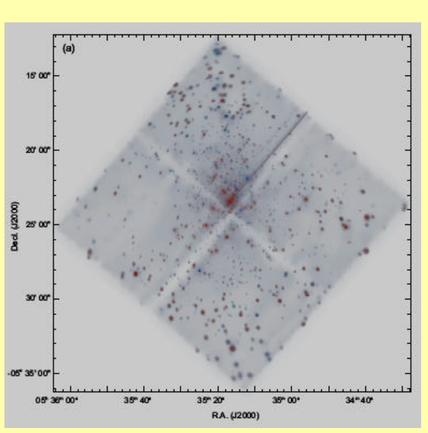
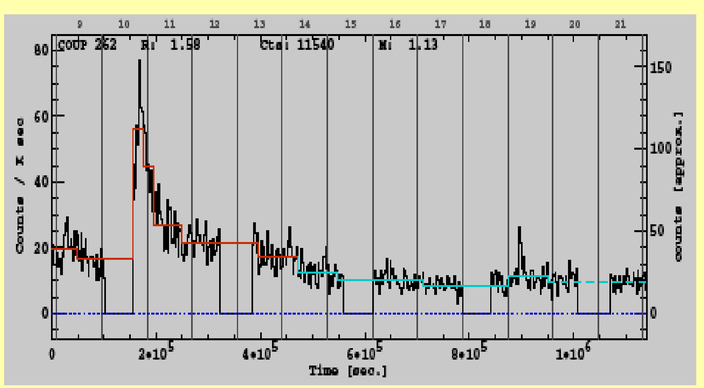
The Orion Nebula
A laboratory for planet formation



Getman et al. 2005
COUP October ApJSuppl Special Issue

On the left above, we see traditional views of Orion stars during the era of planet formation (top: JHK from ESO/VLT; bottom: visual from HST). The right-hand image shows the Chandra view of the region. Nearly all visible stars (except for some M<0.1 M_o stars & BDs) are detected at X-ray levels far above those seen in main sequence stars.



Favata et al. 2005; Wolk et al. 2005
Review in Feigelson et al. (Protostars & Planets V 2006)

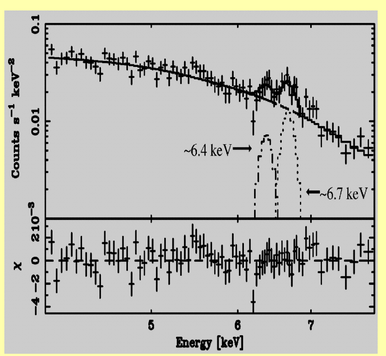
Most PMS stars show flaring during the 13.2 day COUP observation. The evolution of X-ray brightness and temperature, and plasma abundance anomalies, typically resemble properties of solar/stellar flares, indicating that magnetic reconnection events are the main sources of X-ray emission.

Summary

Planets form in cold circumstellar disks that can not emit X-rays. Nonetheless, X-ray studies may yield profound insights into the physical processes of planet formation. Observations of young stellar clusters, such as the recent Chandra Orion Ultradeep Project (COUP), demonstrate that all pre-main sequence stars produce powerful magnetic reconnection flares during the planet formation era. Observations and calculations indicate that the X-rays can penetrate deeply into protoplanetary disks and will be the dominant source of gas ionization. This may have many effects including inducing MHD turbulence which would substantially affect disk viscosity and protoplanet migration. X-ray flares may flash-melt chondrules and produce radioactive isotopes prevalent in the meteoritic record by spallation.

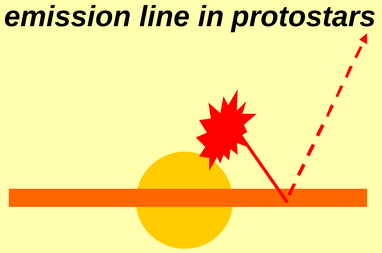
The Constellation-X mission will powerfully propel these investigations and open up new opportunities, such as 6.4 keV line reverberation mapping and measurements of element column densities in protoplanetary disks.

Evidence for X-ray irradiation of protoplanetary disks

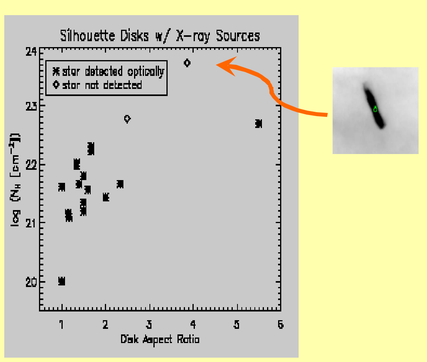


Imanishi et al. 2001; Tsujimoto et al. 2005

Fluorescent 6.4 keV iron emission line in protostars

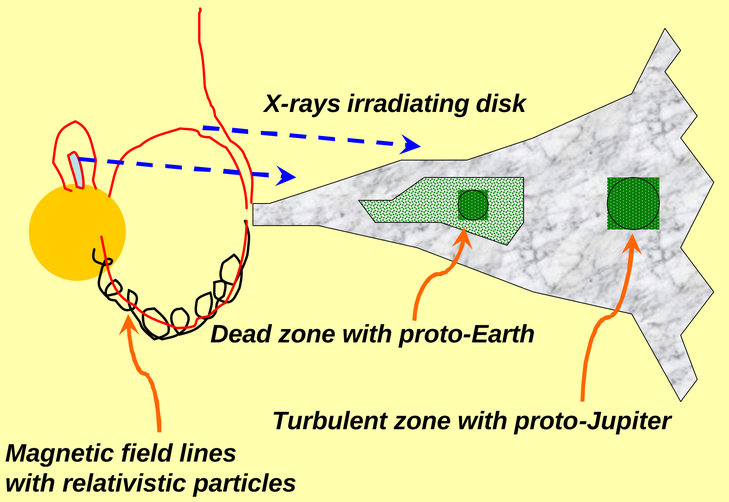


Soft X-ray absorption in edge-on HST proplyds



Kastner et al. 2005

Effects of X-rays on protoplanetary disks



- **PMS X-ray ionization may induce MHD turbulence via the magnetorotational instability. Turbulence is critical for disk viscosity permitting accretion, and for regulating planetesimal growth, disk gaps and Type I/II protoplanetary migration.**
- **PMS X-ray may be the main ionization source at the base of Herbig-Haro outflows from protostars**
- **PMS X-ray ionization will induce non-equilibrium gas/dust heating and ion-molecular chemisty**
- **Flare MeV particles can produce shortlived nuclides by spallation (^{10}Be, ^{41}Ca, ^{21}Ne, …). These enigmatic isotopes are seen in various component of pristine meteorites from the solar nebula.**

Piece of the Allende carbonaceous chondritic meteorite

- **Flare X-ray emission or associated shock waves may melt meteoritic chondrules.**

References in reviews by Feigelson (Cool Stars #13 2005), Glassgold et al. (Chondrites & the Protoplanetary Disk 2006), and Feigelson et al. (Protostars & Planets V 2006)